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Growth performance and intestinal morphometric features of broiler chickens fed on dietary inclusion of yellow mealworm (*Tenebrio molitor*) larvae powder

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Abstract

Background: Climate change and the lack of conventional feed ingredients have made edible insects a highly nutritious alternative to feed production. The use of insects as food may help solve socio-economic and environmental problems around the world and be in line with the United Nations Sustainable Development Goals.

Objective: In this study, the growth performance and intestinal morphology of broiler chickens were evaluated under the influence of adding different levels of *Tenebrio molitor* larvae meal (TM meal) to their diets.

Methods: One hundred and eighty one-day-old broiler chickens were divided into three treatments and five replications (12 chickens/pen). The experimental diets included a control diet and treatments containing 2.5% and 5% TM meal, which were fed to birds in the starter (0–10 days) and grower (11–25 days) stages, and during the final period (26–42 days), all birds were fed a regular finisher diet.

Results: The results showed that the diet containing TM meal had no remarkable effect on the mortality rate and feed intake of broilers ($p > 0.05$). In the starter period, the addition of 2.5% TM meal to broilers' diet increased body weight gain than the control group ($p \leq 0.05$). Also, the use of 2.5% TM meal in the starter period showed a significant effect on reducing the feed conversion ratio, compared to the birds fed by the control diet ($p \leq 0.05$). Besides, the height of the villus, the depth of the crypt and their ratio were not altered among the different treatments ($p > 0.05$).

Conclusions: Overall, it can be concluded that TM meal could improve growth performance in the starter period and had no negative effects on broilers' performance and intestinal morphology in all the periods of the experiment.

KEYWORDS
broiler chickens, growth performance, intestinal morphology, *Tenebrio molitor* larvae meal

1 | INTRODUCTION

Today, world food production is facing the challenges of population growth, climate change and competition for the use of high-quality agricultural land, while experts believe that healthy food has the least environmental risks and the least efficiency of non-renewable resources such as water (FAO, 2011). One of the main problems of the poultry industry is the preparation of feeds that contain all the essential nutrients for the rapid growth of poultry in a short time. The nutritional requirements of monogastric species include high quality and quantity of protein in the diet. The main sources of protein in the broilers' diet are soybean meal and fish meal, which are both associated with several problems such as short supply in the future due to the lack of water for cultivation, rising prices, dependence on imports and competition with human food (Van Huis & Oonincx, 2017). So, many current livestock systems need to be changed and innovated to meet the current and future demand for livestock products. In this regard, research on new ingredients (especially those rich in protein) is necessary. The insect protein content is about 40% to 60% dry matter and fat content is 30% to 40% dry matter, and also the amino acids and essential fatty acids in insects are similar to sources such as fish meal and soybean meal that are commonly used in poultry diets. Of the various types of insects, special attention has been paid to the mealworm. Mealworms, *Tenebrio molitor* L. (Coleoptera: Tenebrionidae), are the brown worm-like larvae of darkling beetles and can be found almost everywhere on the planet; they prefer warm, dark and damp places like under decaying leaves (Makkar et al., 2014). Larvae have different nutritional values depending on their species and stage of development and contain significant amounts of protein, fat, essential vitamins or minerals and amino acids (Rumpled & Schlüter, 2013). Moreover, mealworm is an excellent source of nitrogen. Nitrogen in mealworms is present in the form of D-acetyl glucosamine, a sugar amino acid that forms chitin, which is indigestible to poultry but is fermented in the large intestine by microorganisms (Benzertiha et al., 2020; Sanchez-Muros et al., 2014; Selaledi et al., 2020). Van Huis (2013) observed that by adding mealworms to broilers' diet, the usage of antibiotics was reduced because the diet contained approximately 3% chitin, which increased the population of beneficial intestinal microbiota, such as *Lactobacillus*, and reduced harmful intestinal bacteria, such as *Salmonella* and *Escherichia coli* populations. The safety of mealworms was investigated in different aspects, including antibiotics, toxins, pesticides and heavy metals (EFSA NDA Panel, 2021; Han et al., 2014; Kouřimská & Adámková, 2016). The results of these experiments showed that compared to other types of insects, mealworms had the lowest risk in terms of safety.

Studies have shown that gastrointestinal characteristics affect the efficiency of dietary protein utilisation (Swatson et al., 2002). In particular, among the main indicators of growth, health and function of the intestine is the microscopic structure of the small intestine in terms of villi height and crypt depth, which affects the digestion and absorption of nutrients (Wang & Peng, 2008). Changes in protein source and diet structure have been suggested to have a negative impact on the morphology of broilers in terms of reducing the height of villi and increasing the depth of the crypt (Qaisrani et al., 2014). Although it has been shown that intestinal morphology is affected by changes in poultry diets (Laudadio et al., 2012; Qaisrani et al., 2014), there are few studies on the effect of *T. molitor* larvae meal (TM meal) on the morphometric traits of the intestine. Therefore, this study aimed to determine the growth performance and intestine morphology of broilers fed a TM diet.

2 | MATERIALS AND METHODS

2.1 | Broiler chickens and management

The experiment was performed with 180 one-day-old broilers (Arbor Acres with an average weight of 41 g) in College of Agriculture and Natural Resources, Razi University. The birds were randomly distributed to three treatments with five replicates (12 chickens/pen). The pens were about 1.50-m wide and 1.50-m long, in which there was a feeder, a nipple drinker and chips of wood as a bed. The vaccination schedule and management tips, such as room temperature and humidity, were according to Aviagen's (2014) standard breeding practices.

2.2 | Diets

Experimental treatments included zero levels of TM meal as a control group and the levels of 2.5% and 5% of TM meal as a substitute for the dietary protein source, which was fed in the starter (1–10 days) and grower (11–25 days) periods. The usual finisher diet was provided to all treatments until the end of the period (26–42 days). The broilers had free access to water and food throughout the trial, and rations were provided in the mash forms. Diet adjustment was performed using the recommendations of Aviagen (2014) and NRC (1994), and energy and protein were equal for all treatments in each trial period (crude protein, CP = 237.5 g/kg, metabolisable energy, ME = 3023 kcal/kg at the starter phase and CP = 210 g/kg, ME = 3155 kcal/kg at the grower phase, Table 1). In this study, the amounts of apparent ME obtained from De Marco et al. (2015) experiments on broilers were used.

2.3 | Preparation of mealworms

Mealworms were grown on the wheat bran substrate within 100 plastic boxes of 40 × 27 × 11 cm through the reproduction of adult beetles. Fruits such as carrots and potatoes were used to supply water to the mealworms. After the larvae reached their maximum size, they were separated from the manure by sieving. After 48 h, mealworms were placed in the freezer to be killed and then placed in an oven at 60°C for 20 h to dry. The samples were then analysed to determine the amount of CP, fat, crude fibre, ash, calcium and phosphorus content (AOAC, 2005; Table 2). The amino acid composition of TM meal was determined using high-performance liquid chromatography by the method of Madrid et al. (2012). Besides, by the following formula (ash-free acid

TABLE 1 Ingredients and nutritional level of the diets

Ingredients (g/kg)	Starter period (Days 1–10) C	TM2.5	TM5	Grower period (Days 11–25) C	TM2.5	TM5	Finisher period (Days 26–42)
Corn	475.9	457.7	441.1	574.7	558.0	541.4	637.5
Fish meal	15.5	–	–	49.0	49.0	49.0	48.0
Soybean meal	416.8	404.9	367.1	290.9	253.0	214.9	233.4
Tenebrio molitor larvae meal (TM meal)	—	25	50	—	25	50	–
Wheat bran	–	19.0	48.7	–	29.9	59.7	–
Oil	50.6	50.6	50.6	51.2	51.2	51.2	47.3
Dicalcium phosphate	16.0	15.0	14.3	16.9	16.1	15.4	16.9
Calcium carbonate	9.6	11.5	12.0	5.2	5.7	6.1	4.4
Sodium chloride	3.8	4.0	3.9	3.3	3.2	3.2	3.3
Vitamin mixture[a]	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Mineral mixture[b]	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Threonine	2	2	2	0.9	0.9	0.9	1.2
L-lysine	1.4	2	2.3	0.6	0.9	1.1	0.9
DL-methionine	3.4	3.3	3.0	2.3	2.2	2.1	2.2
Calculated composition, (g/kg)[c]							
Energy (kcal/kg)	3023	3023	3023	3155	3155	3155	3203
CP	237.5	237.5	237.5	210	210	210	190
EE	67.7	72.2	77.7	72.6	78.1	83.6	71.0
CF	39.8	42.2	44.3	33.4	35.4	37.4	30.8
Na	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Lysine	14.3	14.3	14.3	12.2	12.2	12.2	11.0
Methionine	7	6.8	6.7	6	6	6	5.6
Calcium	9.1	9.1	9.1	8.5	8.5	8.5	8
Available phosphorus	4.5	4.5	4.5	4.4	4.4	4.4	4.3

Note: Three dietary treatments: C, control; TM2.5 = 2.5% inclusion level of *Tenebrio molitor*; TM5 = 5% inclusion level

[a]Vitamin premix provided per kilogram of diet: 12,500-IU vitamin A (from retinyl acetate), 3700-IU cholecalciferol, 40-IU vitamin E (from DL-α-tocopheryl acetate), 0.03-mg vitamin B12, 6.4-mg riboflavin, 55-mg niacin (as nicotin amide), 30-mg pantothenic acid (as calcium pantothenate), 3.5-mg menadione (from menadione dimethyl-pyrimidinol), 1.2-mg folic acid, 3-mg thiamine, 7.5-mg pyridoxine, 0.3-mg biotin, 560-mg choline (as choline chloride 60%) and 80-mg ethoxyquin.

[b]Mineral premix provided per kilogram of diet: 80-mg Mn (from $MnSO_4 \cdot H_2O$), 70-mg Zn (from ZnO), 50-mg Fe (from $FeSO_4 \cdot 7H_2O$), 8-mg Cu (from $CuSO_4 \cdot 5H_2O$), 1.5-mg I (from Ca $(IO_3)2 \cdot H_2O$) and 0.35-mg Se (from Na selenite).

[c]CP, crude protein; EE, ether extract; CF, crude fibre.

detergent fibre [%] — acid detergent insoluble protein [%]), the chitin content was calculated (Marono et al., 2015; Table 2).

2.4 | Growth performance

On the first day of the experiment and also on Days 10, 25 and 42, the broilers were weighed to determine body weight gain (BWG), periodically. To measure feed intake (FI), the feed was weighed daily, and the feed residual was measured at the end of Days 10, 25 and 42. Then, through the data obtained from BWG and FI, the feed conversion ratio (FCR) was calculated. Mortality was monitored during the experimental period.

2.5 | Histomorphological investigations

From the middle part of the jejunum and ileum of broilers at 25 days of age, samples about 3-cm long were prepared and washed with phosphate buffer (10 birds per treatment). The samples were then placed in 10% formalin buffer solution for 24 h, after which their solution was changed and kept in formalin buffer until testing. Tissues are typically embedded in paraffin wax blocks, cut to a thickness of 5 μm, mounted on glass slides and stained with haematoxylin and eosin (Biasato et al., 2018). Investigations included the height of the villus, the depth of the crypt and the ratio of the villus height to the crypt depth. The height of the villi from the tips of the villi to the intersection of the villi-crypt

TABLE 2 Nutrient and amino acid composition of the yellow mealworm

Items	TM meal
Analysed composition (g/kg)[a]	
DM	970.2
CP	538.1
EE	280.3
Ash	69.9
CF	75.3
Chitin	56.0
Calcium	35.0
Phosphorus	68.0
Amino acids, %	
Methionine	0.667
Cysteine	0.434
Methionine+ Cysteine	1.101
Lysine	2.748
Arginine	2.591
Threonine	1.899
Leucine	3.931
Isoleucine	2.796
Valine	2.977
Histidine	1.452
Phenylalanine	1.748
Glycine	2.524
Serine	2.164
Proline	3.230
Alanine	3.239
Aspartic acid	3.970
Glutamic acid	0.931

[a]DM, dry matter; CP, crude protein; EE, ether extract; CF, crude fibre.

(a) and crypt depth from the base of the villus to the submucosa (b) was measured using light microscopy (Nikon Eclipse 80i, Nikon Co.; Figure 1).

2.6 | Statistical analysis

To analyse the data, the statistical software SAS 9.4 with the general linear model procedure was used (SAS Institute, 2015). The statistical model of the experiment is as follows:

$Y_{ij} = \mu + T_i + e_{ij}$, where Y is the dependent variable, μ is the overall mean, T is the fixed effect of treatments ($i = C$, TM2.5 or TM5 diet) and e is the random error. Data were also corrected for the effect of gender (male and female). A comparison between means was performed by Duncan's multiple range tests (Duncan, 1955). Orthogonal comparisons were performed to evaluate group comparisons of treatments as well as linear and quadratic responses on SAS software.

3 | RESULTS

3.1 | Chemical composition and growth performance

Table 2 shows the chemical composition and amino acid profile of TM meal. According to our results, TM meal contained about 970.2 g/kg dry matter, 508.1 g/kg CP, 280.3 g/kg ether extract, 69.9 g/kg ash, 75.3 g/kg crude fibre and 56.0 g/kg chitin. Moreover, the calcium and phosphorous contents in the TM meal were 35.0 and 68.0 g/kg, respectively.

The health status of the chickens was checked throughout the rearing period. According to the results of this experiment, no remarkable difference was observed between the experimental treatments regarding the mortality rate of broiler chickens ($p > 0.05$). Moreover, according to Table 3, the dietary treatments had no remarkable impact on the FI of broilers in all the experimental periods ($p > 0.05$). In addition, broilers fed a diet containing TM meal had a greater BWG than the control group in the starter period (1–10 days; $p \leq 0.05$). The greatest BWG belonged to the diet containing 2.5% TM meal, which was significantly different from the control group (186.27 vs. 169.25 g, $p \leq 0.05$; Table 3). Besides, a quadratic response was found among treatments on BWG in the starter period ($p = 0.040$). According to our results, no remarkable impact of experimental diets was seen on the BWG in the other periods of the recent trial ($p > 0.05$). In most of the studied periods, there was no significant effect between treatments in terms

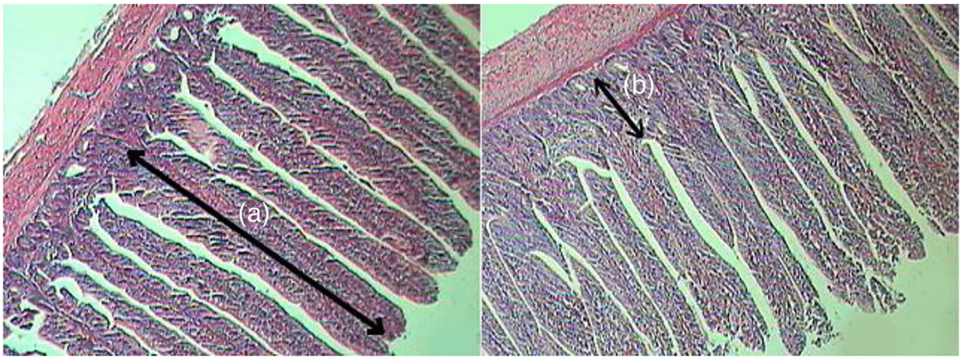

FIGURE 1 Morphometric measurements of the villus height (a) and the crypt depth (b) in the jejunum and ileum segments

TABLE 3 Growth performance of the broiler chicks fed the TM meal diet

Items[a]	BWG (g)				FI (g)				FCR (g/g)			
	1–10d	11–25d	26–42d	1–42d	1–10d	11–25d	26–42d	1–42d	1–10d	11–25d	26–42d	1–42d
C	169.2b	668.5	1343.1	2260.6	222.6	1186.4	2739.0	4283.7	1.32	1.79	2.04	1.90
TM2.5	186.2a	633.9	1392.8	2287.7	231.8	1225.7	2786.1	4381.2	1.25	1.93	2.00	1.92
TM5	178.2ab	643.8	1341.4	2242.5	227.8	1190.0	2736.9	4295.3	1.28	1.86	2.04	1.92
SEM[b]	3.014	11.93	18.14	21.75	2.30	9.95	21.47	25.66	0.01	0.03	0.02	0.01
p-value	0.05	0.50	0.45	0.72	0.28	0.21	0.60	0.25	0.12	0.22	0.80	0.78
Orthogonal contrasts (*p*-value)												
C vs. TM	0.034	0.272	0.548	0.928	0.156	0.306	0.641	0.318	0.068	0.140	0.712	0.498
C vs. TM2.5	0.018	0.268	0.290	0.637	0.119	0.115	0.404	0.133	0.044	0.088	0.562	0.538
C vs. TM5	0.177	0.422	0.970	0.751	0.364	0.879	0.970	0.850	0.247	0.397	0.953	0.575
TM2.5 vs. TM5	0.225	0.746	0.274	0.434	0.477	0.149	0.384	0.181	0.322	0.347	0.601	0.955
Linear	0.177	0.422	0.970	0.751	0.364	0.879	0.970	0.850	0.247	0.397	0.953	0.575
Quadratic	0.040	0.405	0.218	0.470	0.189	0.086	0.327	0.105	0.082	0.128	0.526	0.696

[a]Three dietary treatments: C = control; TM2.5 = 2.5% inclusion level of *Tenebrio molitor*; TM5 = 5% inclusion level.
BWG, body weight gain; FCR, feed conversion ratio; FI, feed intake.
[b]Standard error of the mean.
Means with different superscripts in columns differ significantly ($p \leq 0.05$).

TABLE 4 Intestinal morphometric measurements of broilers fed on the TM meal diets

Items[a]	Jejunum Villus height (μm)	Jejunum Crypt depth (μm)	Jejunum Villus height/crypt depth ratio	Ileum Villus height (μm)	Ileum Crypt depth (μm)	Ileum Villus height/crypt depth ratio
C	1399.16	279.16	5.02	1326.33	280.33	4.77
TM2.5	1434.50	287.66	4.99	1397.50	284.50	4.93
TM5	1544.33	292.50	5.29	1380.83	277.83	4.98
SEM[b]	32.50	5.09	0.09	26.42	4.99	0.11
p value	0.17	0.58	0.40	0.54	0.87	0.76
Orthogonal contrasts (*p* value)						
C vs. TM	0.191	0.341	0.567	0.290	0.941	0.481
C vs. TM2.5	0.650	0.517	0.907	0.299	0.751	0.599
C vs. TM5	0.076	0.314	0.275	0.423	0.849	0.486
TM2.5 vs. TM5	0.170	0.711	0.230	0.804	0.613	0.861
Linear	0.076	0.314	0.275	0.423	0.849	0.486
Quadratic	0.581	0.871	0.442	0.455	0.635	0.838

[a]Three dietary treatments: C = control; TM2.5 = 2.5% inclusion level of *Tenebrio molitor*; TM5 = 5% inclusion level.
[b]Standard error of the mean.
Means with different superscripts in columns differ significantly ($p \leq 0.05$).

of FCR, except for the starter period, in which according to orthogonal comparisons, FCR decreased with 2.5% TM meal than the control group ($p = 0.044$; Table 3).

3.2 | Histomorphology

The intestinal morphometric measurements under the effect of different levels of TM meals are reported in Table 4. According to the results, villi height, crypt depth and their ratio were not changed under the influence of the experimental diets ($p > 0.05$).

4 | DISCUSSION

The nutrient composition of the TM meal provided in our experiment was in the range found in the study of Hong et al. (2020; Table 2). The protein content of TM meal (538.1 g/kg in a recent study) was close to the protein content of common feed components such as soybean meal (440–480 g/kg) and fish meal (500–600 g/kg) used in the poultry industry (Nascimento Filho et al., 2021). However, TM meal contains a greater amount of ether extract (280.3 g/kg) than soybean meal (216.0 g/kg) and fish meal (117.0 g/kg; Nascimento Filho et al., 2021). In addition, the data in Table 2 showed that TM meal had the same or higher levels of most essential amino acids than substances such as soybean meal and fish meal (Hong et al., 2020). These results show that TM meal is a good quality substance that is used in the formulation of diets to prepare the chicken's amino acid needs. The induced or natural conditions included in the production or processing of TM meals could be the reason for the variety in the nutrient composition that was observed in different studies (Makkar et al., 2014).

In the current study, no remarkable difference was observed between the control diet and diets containing TM meal on the FI of broilers, so it can be concluded that TM meal, especially at low inclusion levels used in the present study, was palatable for broilers, and it would not negatively affect their FI. According to the literature, increasing insect levels in poultry diets reduced FI due to the imbalance of nutrients and amino acids in the diet (Moula & Detilleux, 2019). Additionally, high levels of chitin in the skeleton of insects were introduced as other effective factors in reducing FI by increasing the levels of insects in poultry diets due to its low digestibility (Moula & Detilleux, 2019). In our study, low levels of TM meal (2.5% and 5%) in the diet of broilers were used, and the amount of chitin in TM meal was about 5.6% per kg of dry matter (Table 2). Moreover, all diets were equal in terms of energy and protein in all periods, so no negative effect was observed on FI, and all diets had the same performance in this regard. Ballitoc and Sun (2013) investigated the effect of using the levels of 0%, 0.5%, 1%, 2% and 10% TM meal on the performance of broilers at weeks 2 to 5. It was shown that at the end of the rearing period, the highest FI after the control groups was related to the treatment containing 1% TM meal, and the lowest FI was related to the treatment containing 10% TM meal. According to the results of this experiment, Elahi et al. (2020) stated that up to 8% TM meal could be used in the diet of broilers without any remarkable effect on FI.

Based on our findings, the BWG was greater in broilers fed TM meal than in those fed the control diet during the starter period; however, in other periods of the trial, no significant difference was observed between treatments regarding BWG. Insect meal has been shown to be more similar to animal sources of protein than plant origin protein (Hong et al., 2020). Cromwell (1998) showed that animal protein sources have higher bioavailability than plant-based protein sources. Also, another reason for the higher efficiency of nutrients in the body of birds fed with TM meal can be attributed to the prebiotic effect of chitin in the skeleton of insects. One of the important functions of prebiotics in the body is to reduce the population of harmful microorganisms in the intestine and improve gastrointestinal health (Sedgh-Gooya et al., 2021). In addition, there are reports that the use of prebiotics in broiler diets has increased the intestinal digestibility of nutrients (Bedford, 2000; Rehman et al., 2020). Elahi et al. (2020) investigated the influence of using levels of 0%, 2%, 4% and 8% dried or 10.48% live mealworm in broiler diets on their growth performance. According to their results, containing 4% TM meal in the diet had the potential to increase the body weight of broilers, especially during the starter period of the experiment. In contrast, Biasato et al. (2016) and Bovera et al. (2015) reported that TM meal did not change the BWG of broilers, compared to the control diet.

In this study, no significant effect of dietary treatments was observed on the FCR, except for the starter period, which decreased by 2.5% TM meal, compared to the control diet. The decrease in FCR in the starter period was due to the increase in the weight of broilers by consuming similar amounts of feed, which shows the higher nutrient efficiency of TM meal, compared to the control diet. One reason for this better performance can be attributed to the prebiotic role of chitin. Bovera et al. (2016) reported that replacing soybean meal with TM meal reduced the apparent ileal digestibility coefficients of dry and organic matter by 2% in broilers fed a diet containing TM meal, compared to broilers fed soybean meal. TM meal also had lower protein digestibility coefficients of 8.2%. Interestingly, the reduction in nutrient digestibility observed in the group containing TM meal did not affect growth performance, and broilers from both experimental groups had the same slaughter weight. Besides, broilers fed TM meal showed an improved FCR, compared to the control group (Bovera et al., 2016). According to the findings of Ballitoc and Sun (2013), when TM meal was added from 0% to 10% in the diet of broilers, a decreasing trend in FCR was observed. Similar to the results of a recent experiment, Elahi et al. (2020) showed that the addition of 4% TM meal to broiler diets improved the FCR in the starter period. Besides, Benzertiha et al. (2019) reported that adding low levels of TM meal (0.2% and 0.3%) to broiler diets did not affect their FCR. Differences in the dose used, age and type of birds can be the reasons for differences in the results of different experiments.

According to our results, the morphometric features of the jejunum and ileum were not changed between different treatments, thus showing no negative effects on nutrient metabolism, yield and animal health as a result of the replacement of TM meal in the diet of broilers. Similar findings were reported in the study by Biasato et al. (2016), who observed that the inclusion of 7.5% TM meal in the diet of broilers did not have a significant effect on the intestinal morphometric indices. Changes in protein source and diet structure have been shown to have a negative impact on the morphology of the small intestine in broilers in terms of decreasing villus height and increasing crypt depth (Qaisrani et al., 2014). According to Biasato et al. (2018), the use of high levels of TM meal (15%) in poultry diets altered their intestinal morphology, so they suggested that low levels of TM meal were better and should be preferred. In the present study, low levels of TM meal were used, and no negative effects were observed on morphometric indices, which is in accordance with the results of Biasato et al. (2016).

5 | CONCLUSION

The use of TM meal in broilers' diet can lead to improved BWG and efficient use of feed in the starter period (1–10 days). Among the different levels of TM meal used in the recent experiment regarding broiler performance, the best result was obtained with the level of 2.5%. The height of the villus, the depth of the crypt depth and the villus height to crypt depth ratio were not influenced by dietary treatments. Therefore, it could be concluded that TM meal was safe and had no negative effects on broilers.

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CONFLICT OF INTEREST

The authors have no conflict of interest to be declare.

ETHICS STATEMENT

All experimental protocols adhered to the guidelines approved by the Animal Ethics Committee of Razi University, Kermanshah, Iran, and were in accordance with the EU standards for the protection of animals and/or feed legislation.

AUTHOR CONTRIBUTIONS STATEMENT

Shadi Sedgh-Gooya: Performed experiment, collected and statistically analyzed the experimental data, prepared the result tables and wrote the primary draft of the manuscript.

Mehran Torki: Designed and supervised the research, Revised and submit the draft manuscript.

Maryam Darbemamieh: Consultant of insect mass-production, Revising and correcting the manuscript.

Hassan Khamisabadi: Resources.

Alireza Abdolmohamadi: Consultant of statistical data analysis.

DATA AVAILABILITY STATEMENT

The pure data sheet would be available at request.

PEER REVIEW

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